Elastic Scattering and High Mass Exclusive Dijets at DØ ($\sqrt{s}$=1.96 TeV)

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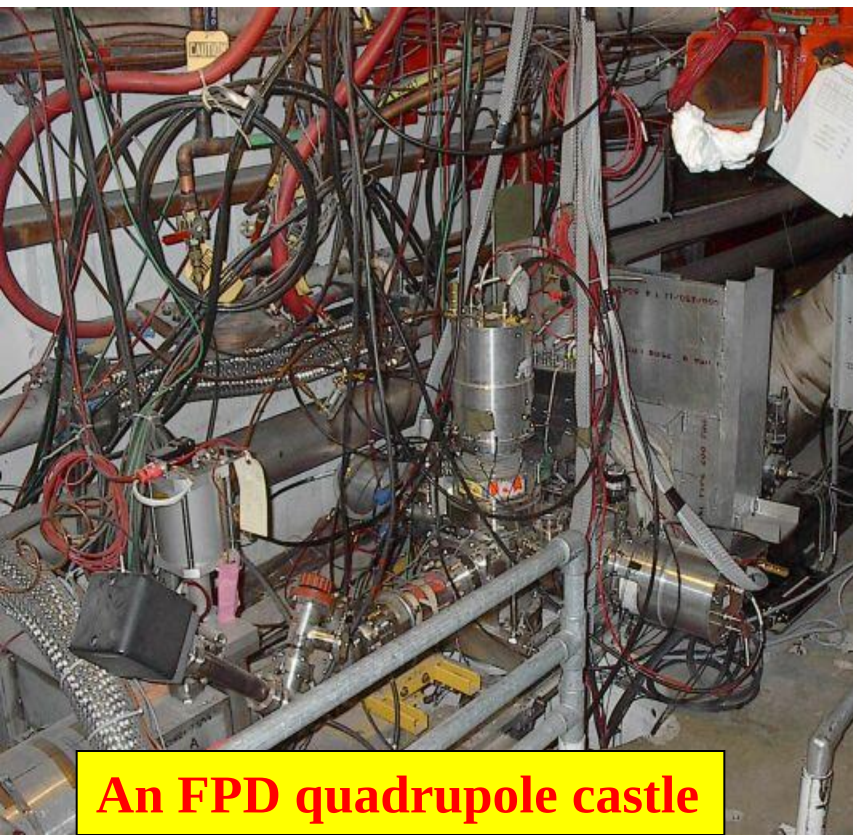
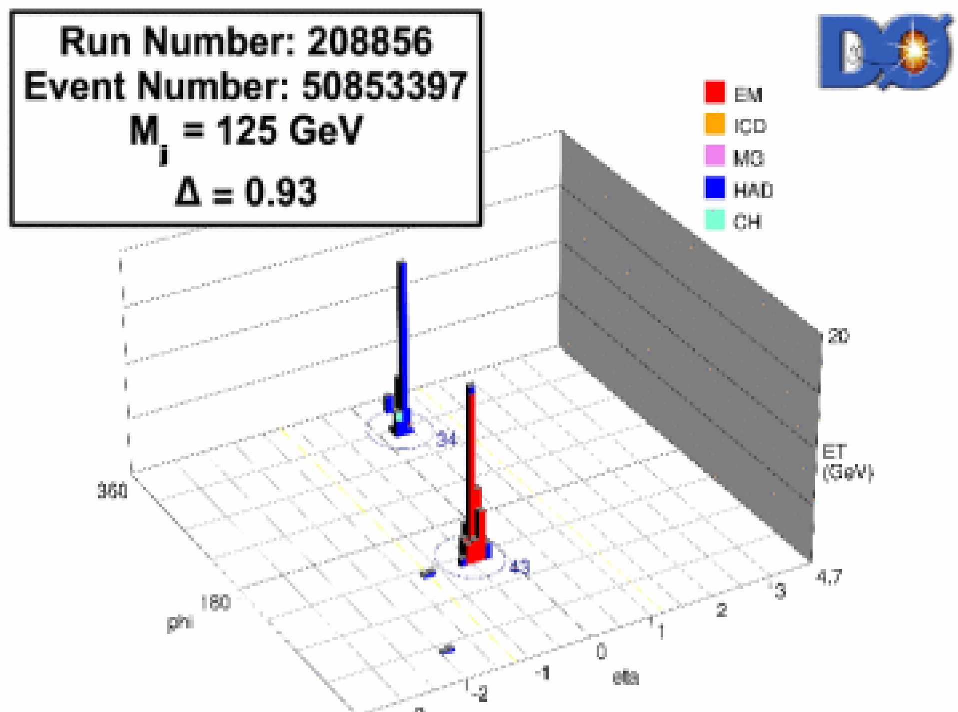
on behalf of DØ Collaboration



An FPD quadrupole castle



An exclusive dijet candidate event

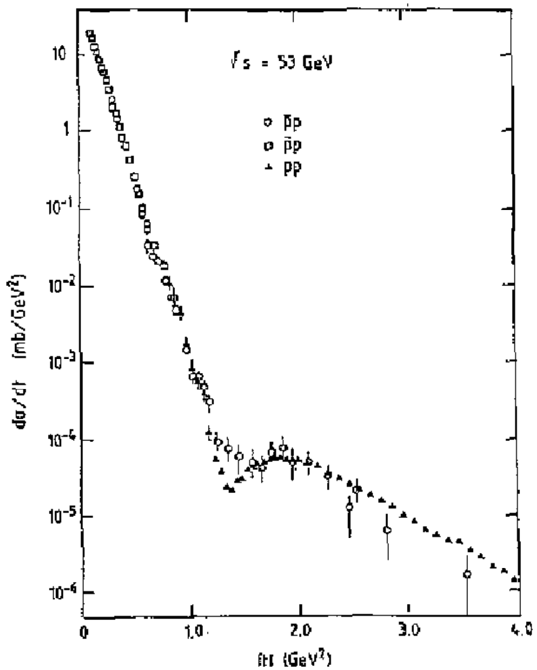
Elastic Scattering

- The particles after scattering are the same as the incident particles
- $\xi = \Delta p/p = 0$ for elastic events; $t = -(p_i - p_f)^2$
- The cross section can be written as:

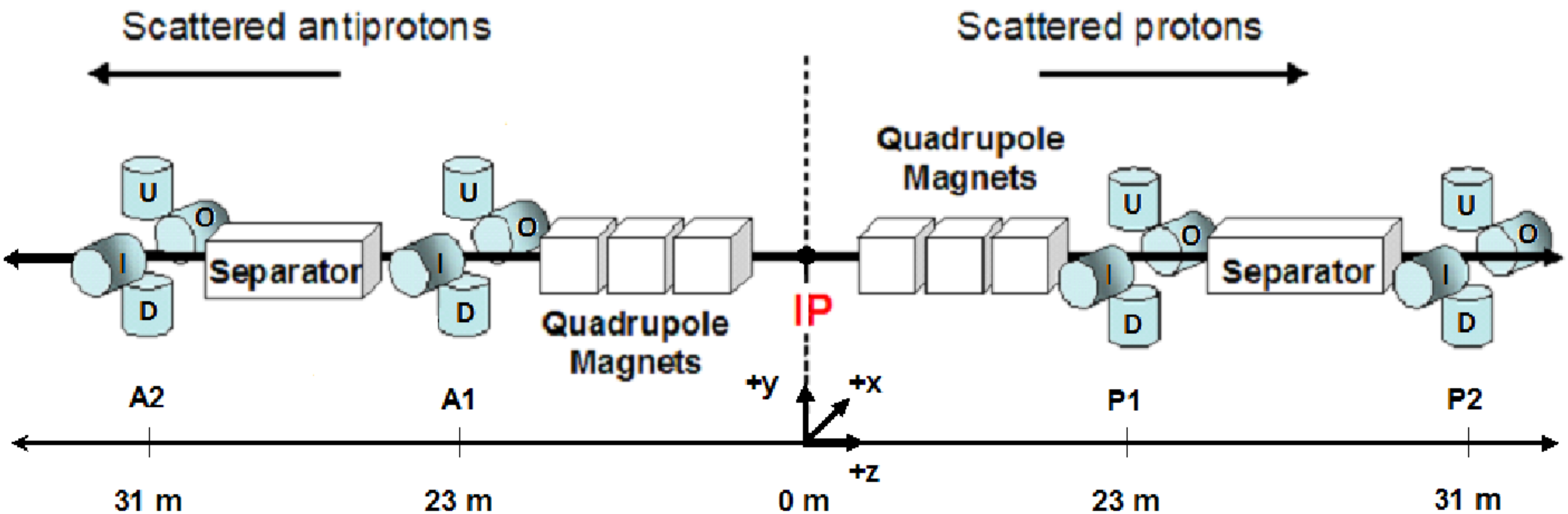
$$\frac{d\sigma/dt}{(d\sigma/dt)_{t=0}} = e^{bt} \cong 1 - b(p\theta)^2$$

- This has the same form as light diffracting from a small absorbing disk, hence processes with an intact proton (or two) are called diffractive phenomena
- Characterized by a steeply falling |t| distribution and a dip where the slope becomes much flatter

Elastic "dip" Structure from Phys. Rev. Lett. 54, 2180 (1985).



Forward Proton Detector

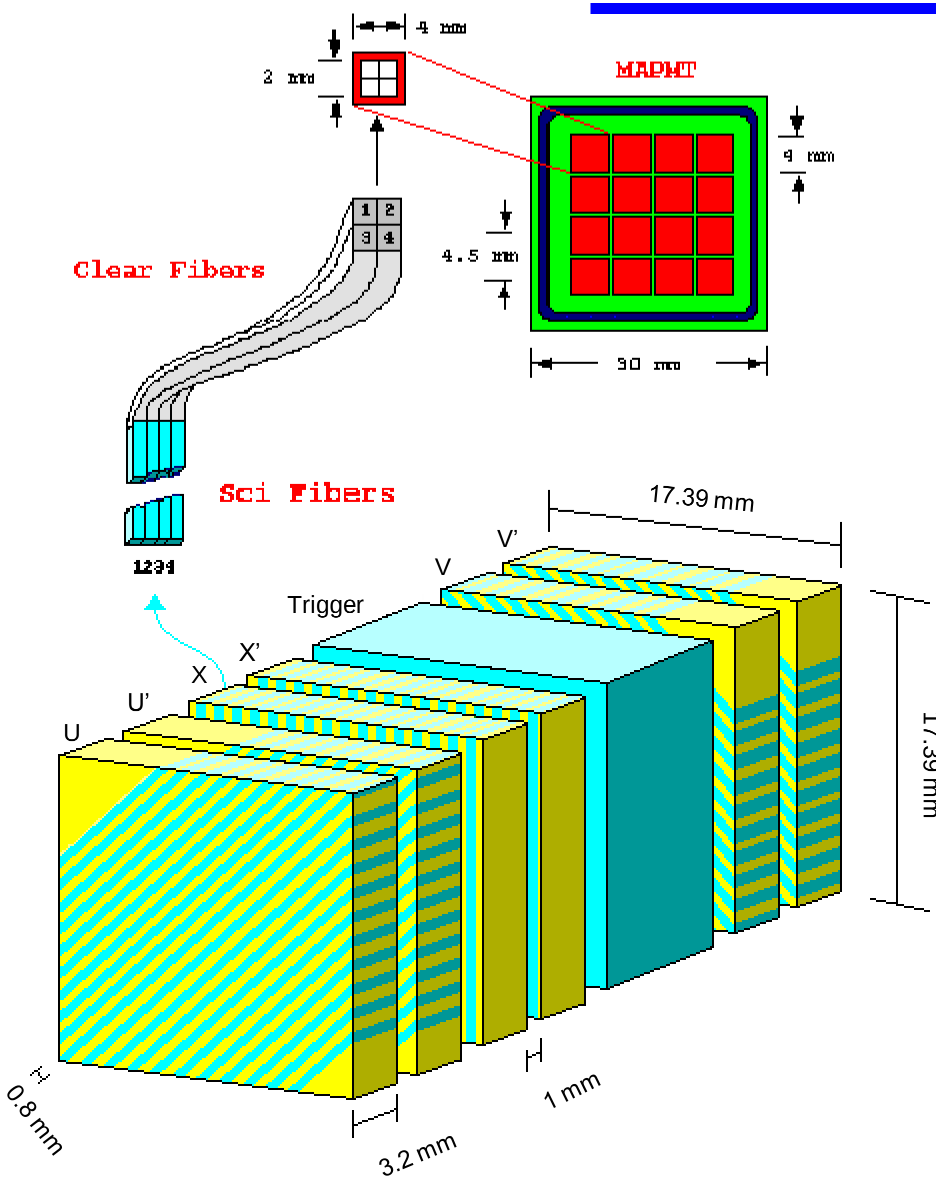


⇨There are eight quadrupole spectrometers (Up, Down, In, Out) on the outgoing proton (P) and anti-proton (A) sides each comprised of two detectors (1, 2)

⇨Use Tevatron lattice and scintillating fiber hits to reconstruct ξ and $|t|$ of scattered protons (anti-protons)

⇨The acceptance for $|t|>|t_{min}|$ where t_{min} is a function of pot position: for standard operating conditions $|t| > 0.8$ GeV^2

FPD Detectors



- 3 layers in detector: U and V at 45° degrees to X, 90° degrees to each other
- Each layer has two planes (prime and unprimed) offset by ~2/3 fiber
- Each channel contains four fibers
- Two detectors in a spectrometer
- Scintillator for timing

Large β* Store

- In 2005 DØ proposed a store with special optics to maximize the |t| acceptance of the FPD
- In February 2006, the accelerator was run with the injection tune, β^* =1.6m (about 5x larger than normal)
- Only 1 proton and 1 anti-proton bunch were injected
- Separators OFF (no worries about parasitic collisions with only one bunch)
- Integrated Luminosity (30   4 nb^{-1}) was determined by comparing the number of jets from Run IIA measurements with the number in the Large β^* store
- A total of 20 million events were recorded with a special FPD trigger list

Basics of Proton Track Finding

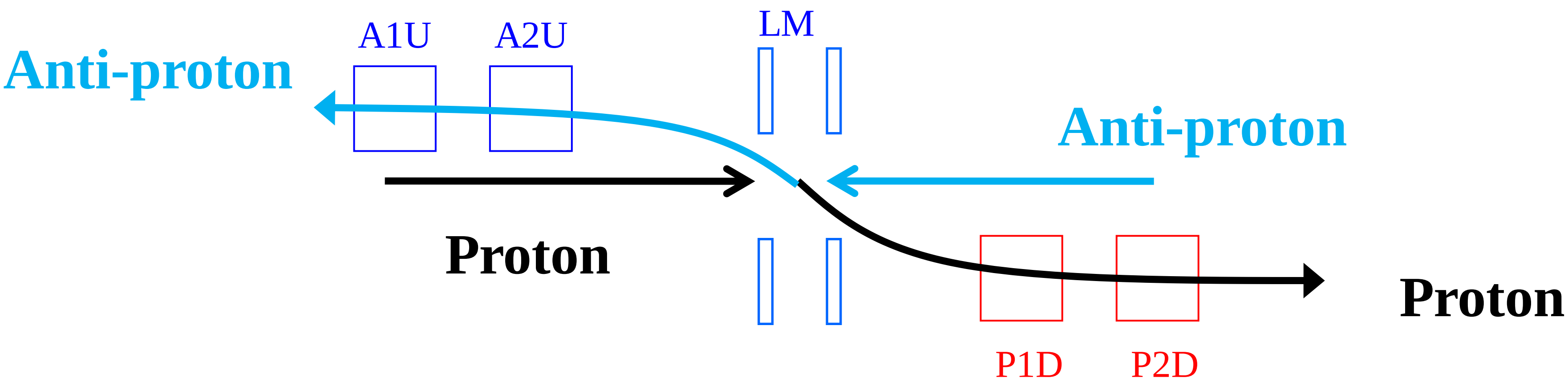
- **Alignment**
  - Use over-constrained tracks that pass through horizontal and vertical detectors to do relative alignment of detectors, and use hit distributions to align detectors with respect to beam.

- **Hit Finding**
  - Require less than 5 hit fibers per layer (suppresses beam background)
  - Use intersection of fiber layers to determine a hit

- **Track Reconstruction**
  - Reconstruct the tracks in the forward detectors if there are good hits in both detectors
  - Use the aligned hit values and the Tevatron lattice transport equations to reconstruct track.

Elastic Spectrometer Combinations

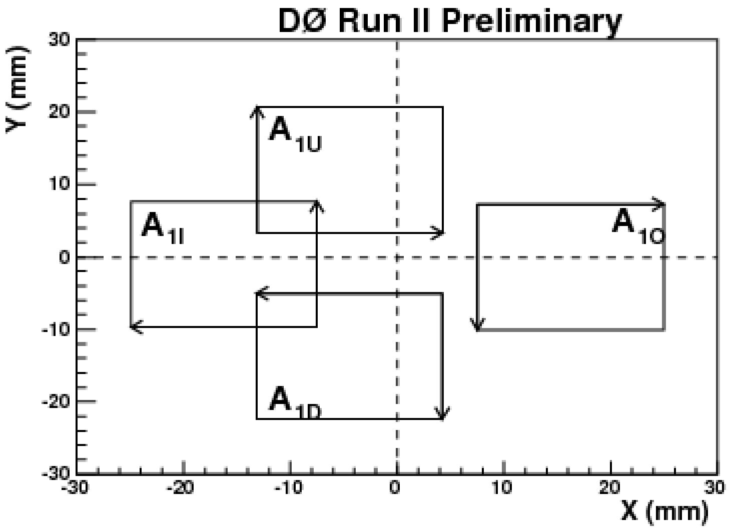
Elastic events have tracks in diagonally opposite spectrometers

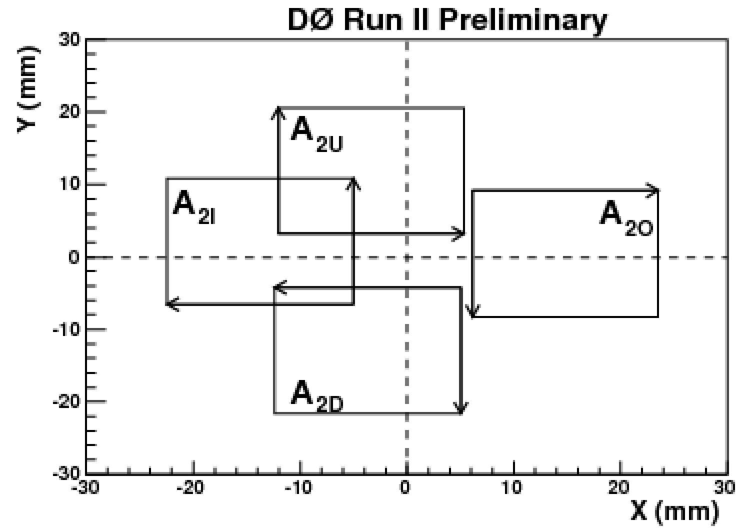


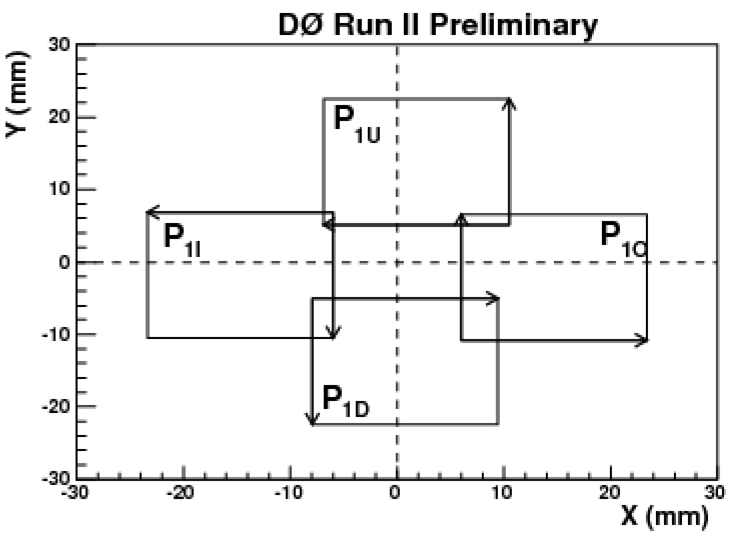
Momentum dispersion in horizontal plane results in more halo (beam background) in the IN/OUT detectors, so concentrate on vertical plane AU-PD and AD-PU to maximize |t| acceptance while minimizing background

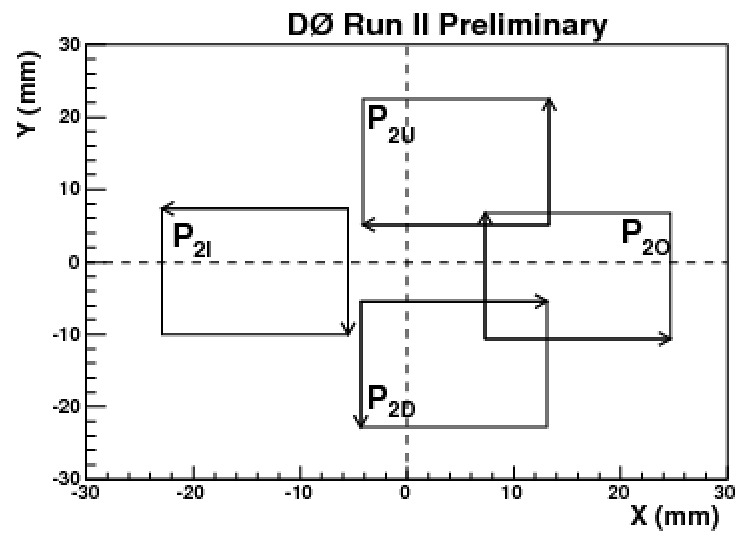
AU-PD combination has the best |t| acceptance

Detector Positions after Alignment

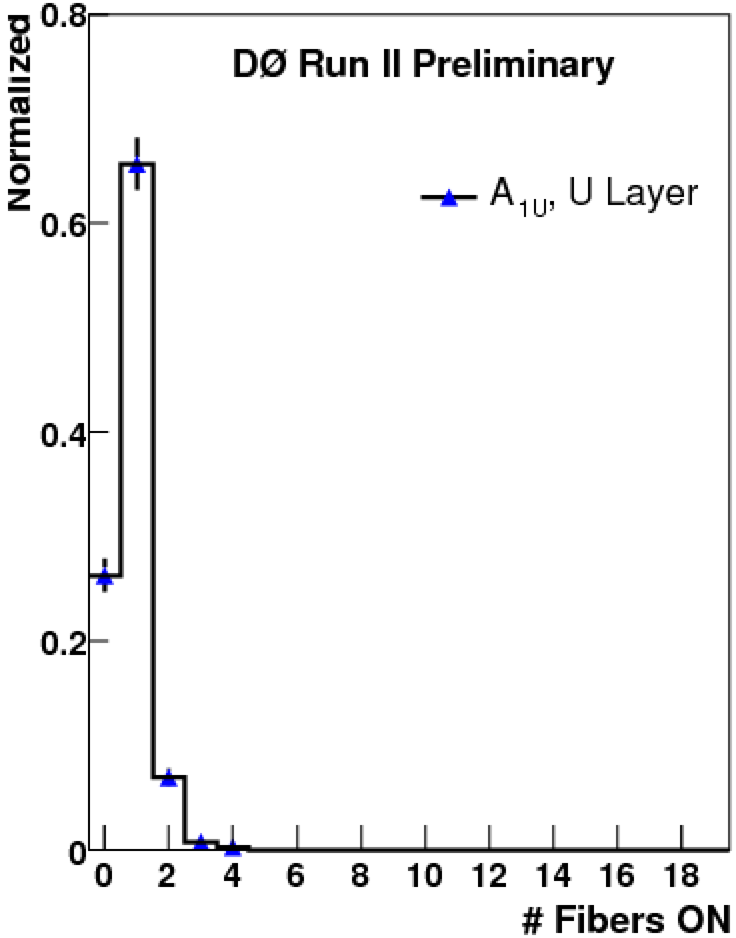


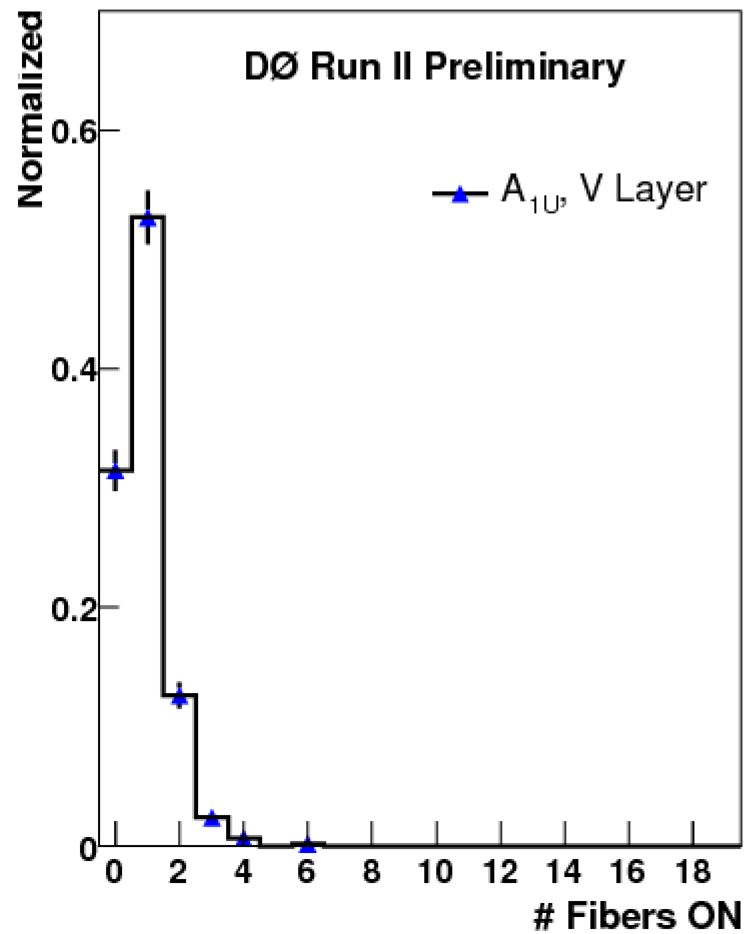






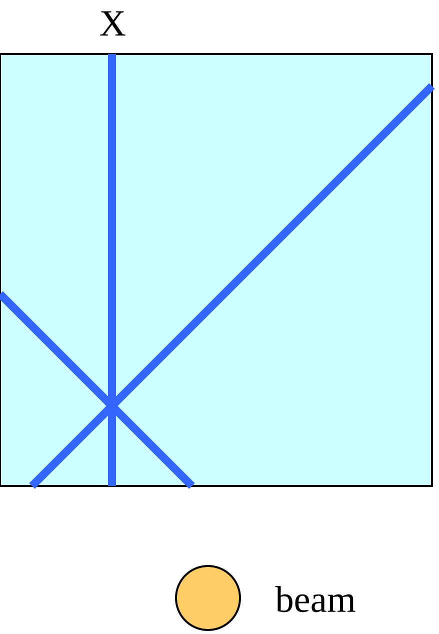
Layer Multiplicity for Elastic Candidates

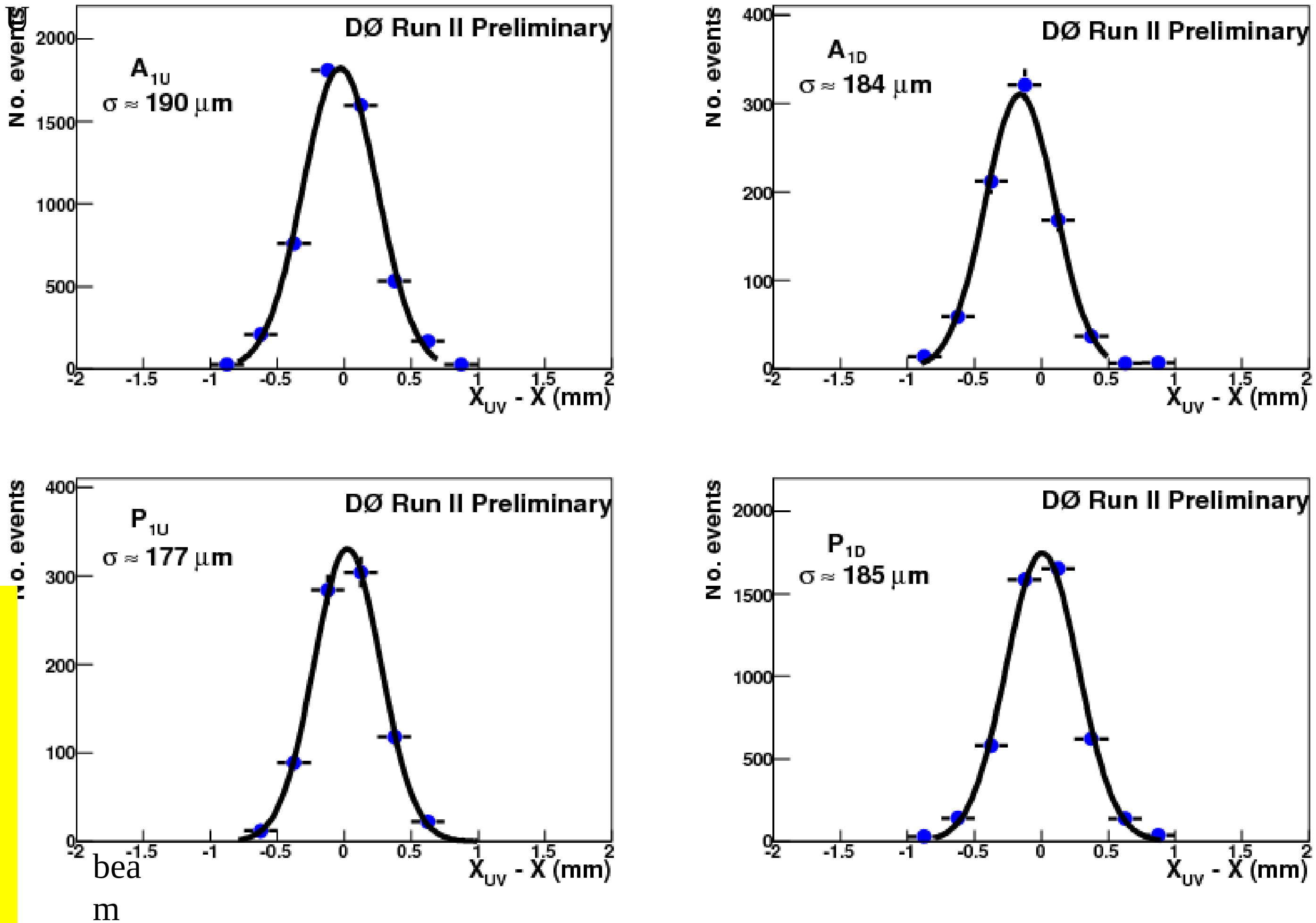




Elastic events have low fiber multiplicity

Detector Resolution

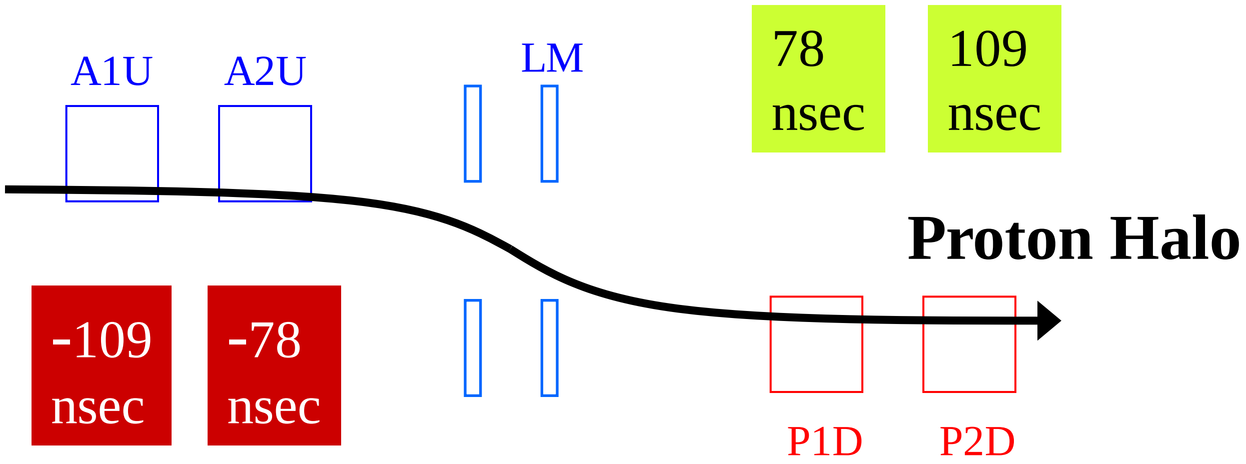




Can measure x coordinate from overlap of u and v fibers or directly from x fiber

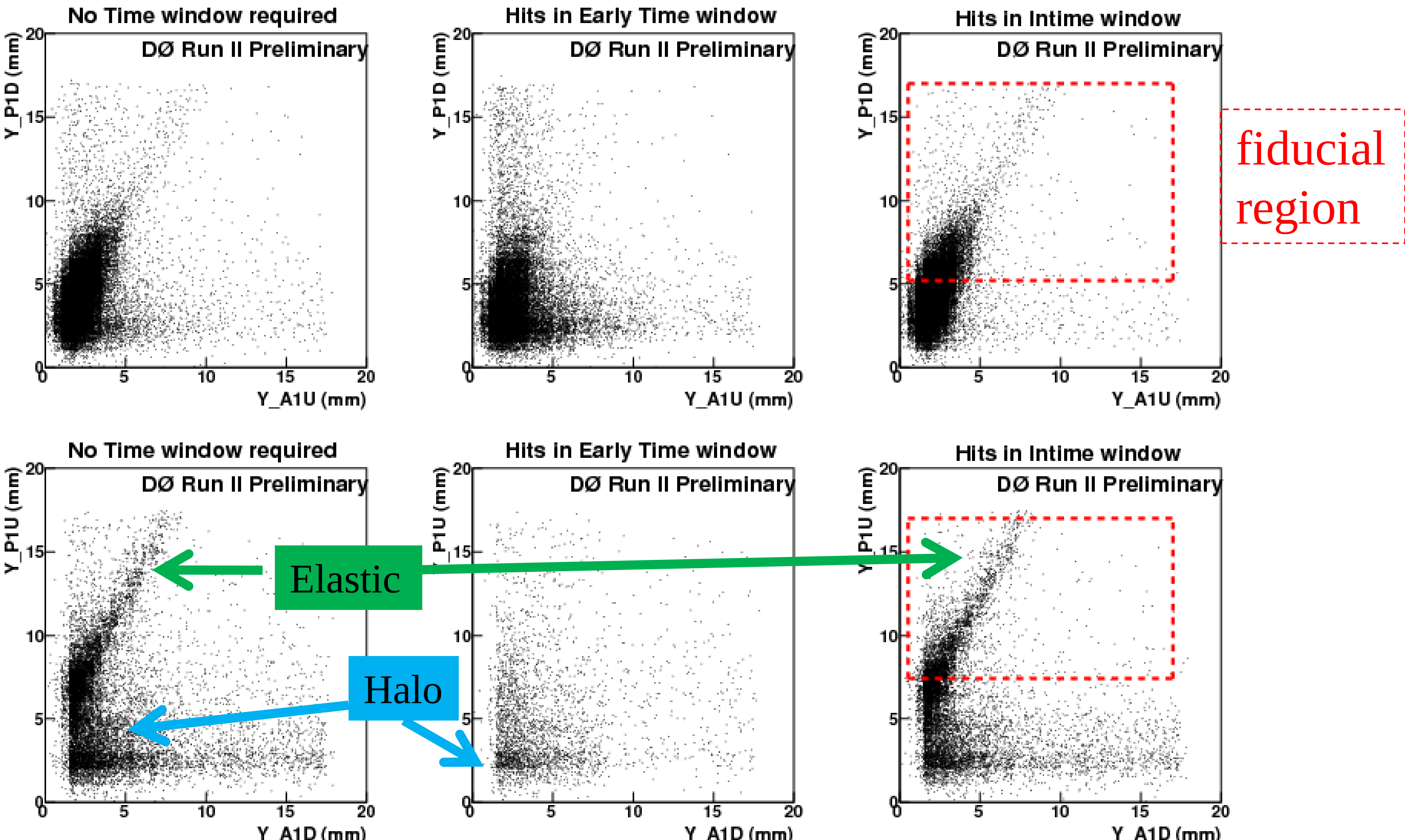
Use $x_{uv}-x_x=\sqrt{2}\sigma$ to determine resolution 180-190 μm

Halo Rejection



- The in-time bit is set if a pulse detected in the in-time window (consistent with a proton originating from the IP)
- The halo bit is set if a pulse detected in early time window (consistent with a halo proton)
- We can reject a large fraction of halo events using the timing scintillators (depending on the pot locations)

Correlations Between Detectors



Measuring Cross Section

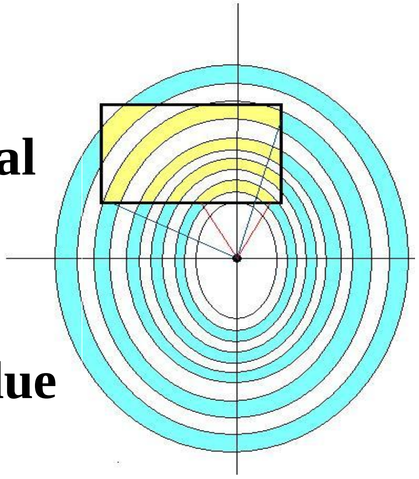
1. Count elastic events
2. Correct for acceptance and efficiency
3. Unsmearing correction for |t| resolution
4. Subtract residual halo background
5. Divide by luminosity
6. Take weighted average of four measurements
   (2 elastic configurations each with two pot positions)

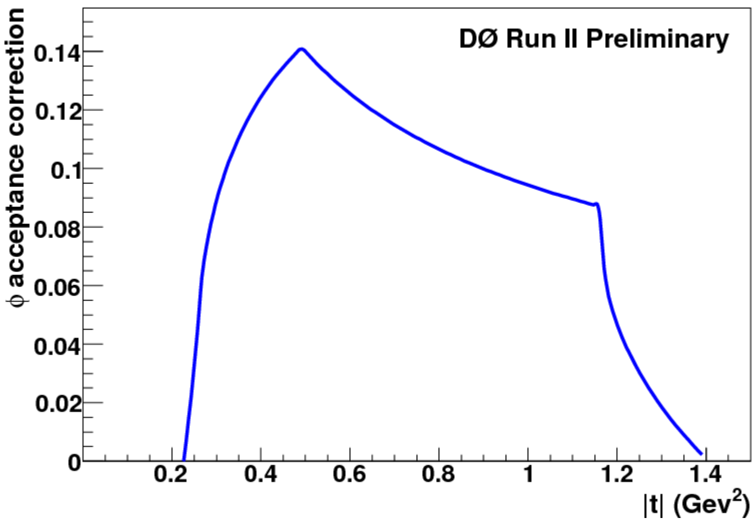
$$\boxed{\frac{d\sigma}{dt} = \frac{1}{L \cdot A \cdot \varepsilon} \frac{dN}{dt}}$$

Correcting Cross Section

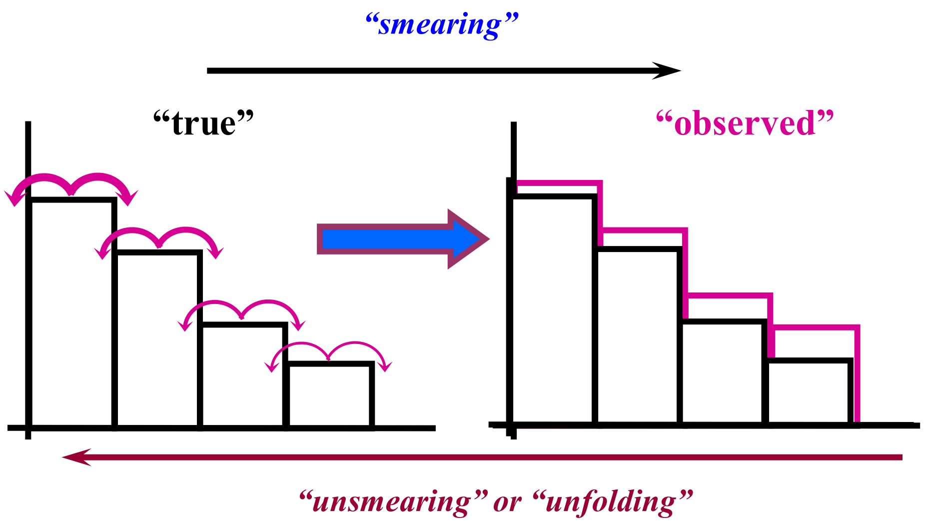
Corrections:

1) ϕ acceptance (geometrical loss due to finite size of opposite spectrometer)





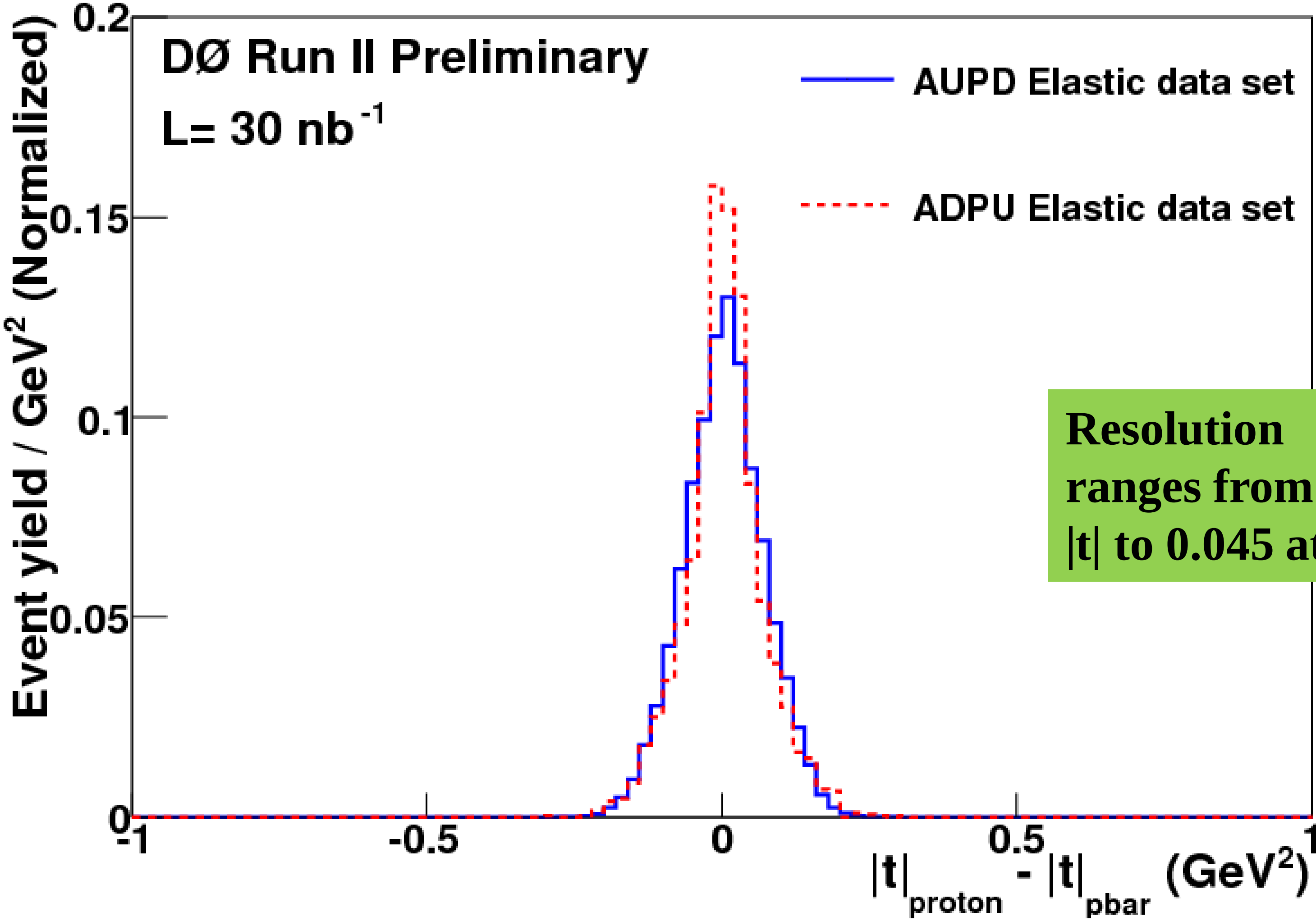
2) Unsmearing correction due to beam divergence, |t| resolution (standard approach using ansatz function)



3) Efficiency: use triggers requiring A1-P1 or A2-P2 hits, offline demand 3rd hit, then measure efficiency of 4th detector

4) Use side bands to measure and subtract background

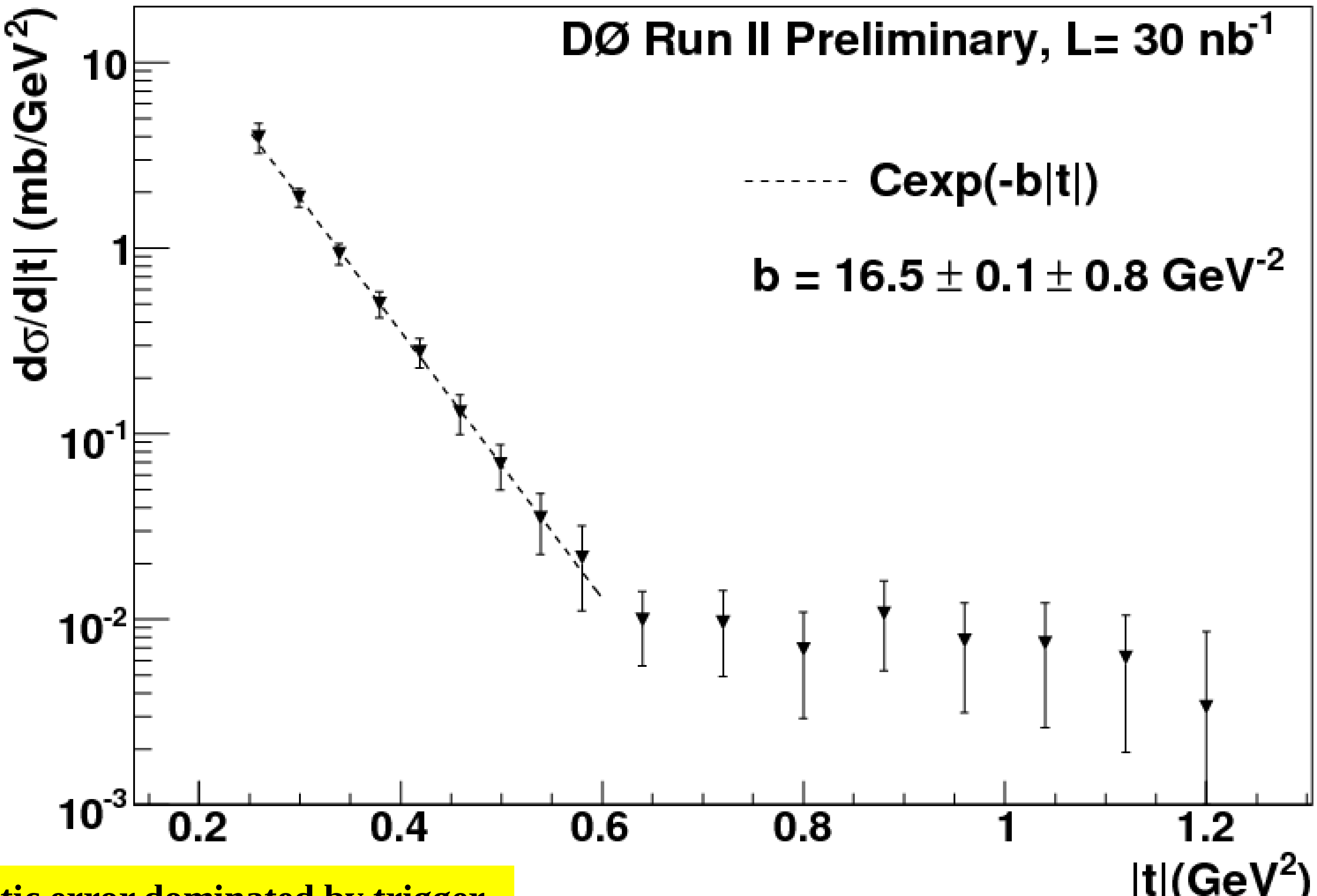
$\delta|t|$



Resolution ranges from 0.02 at low |t| to 0.045 at high |t|

Observe expected colinearity between proton and anti-proton

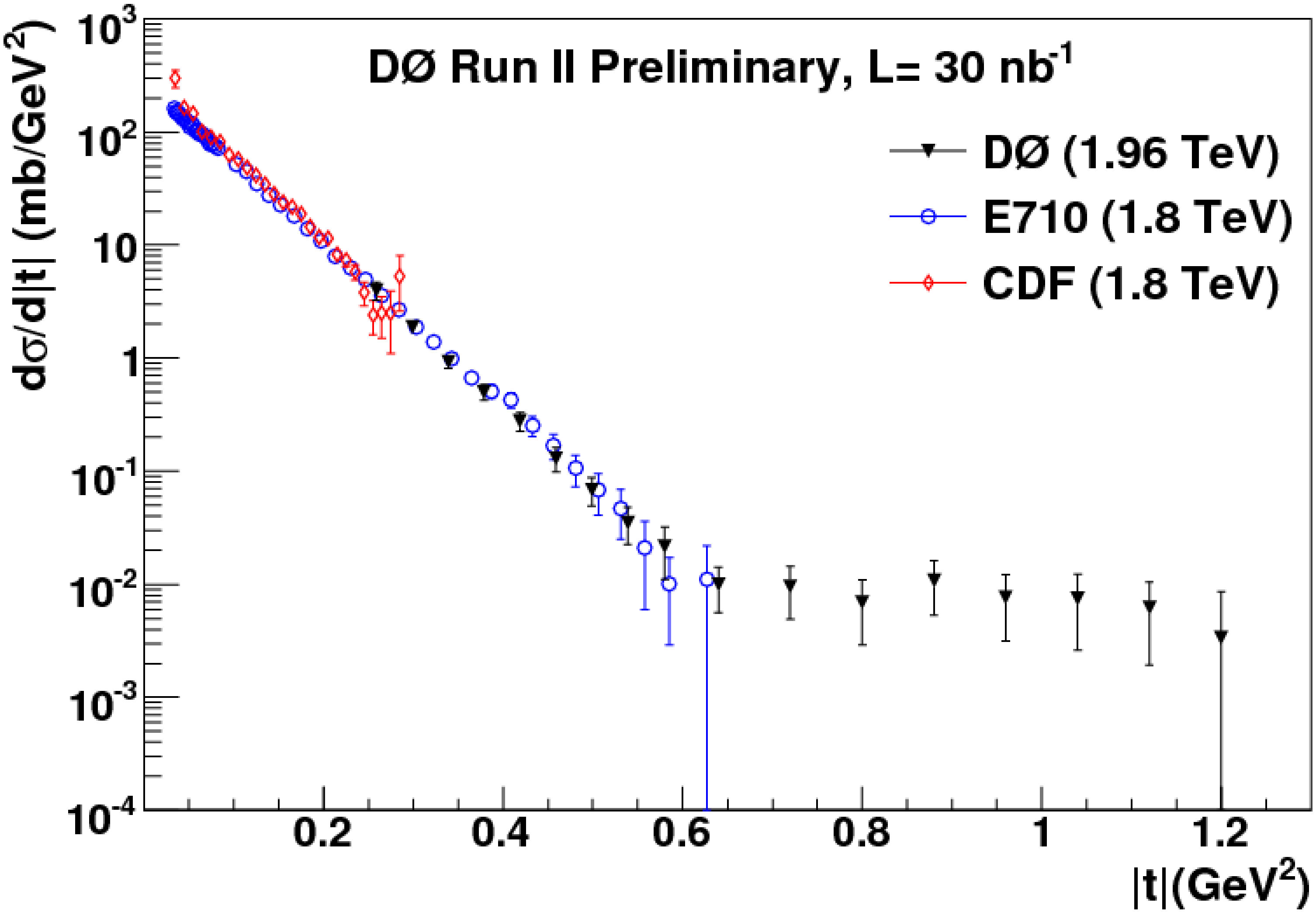
Measurement of Elastic Slope (b)



- Systematic error dominated by trigger efficiency correction
- Second biggest uncertainty (alignment) = ± 0.3 GeV^2

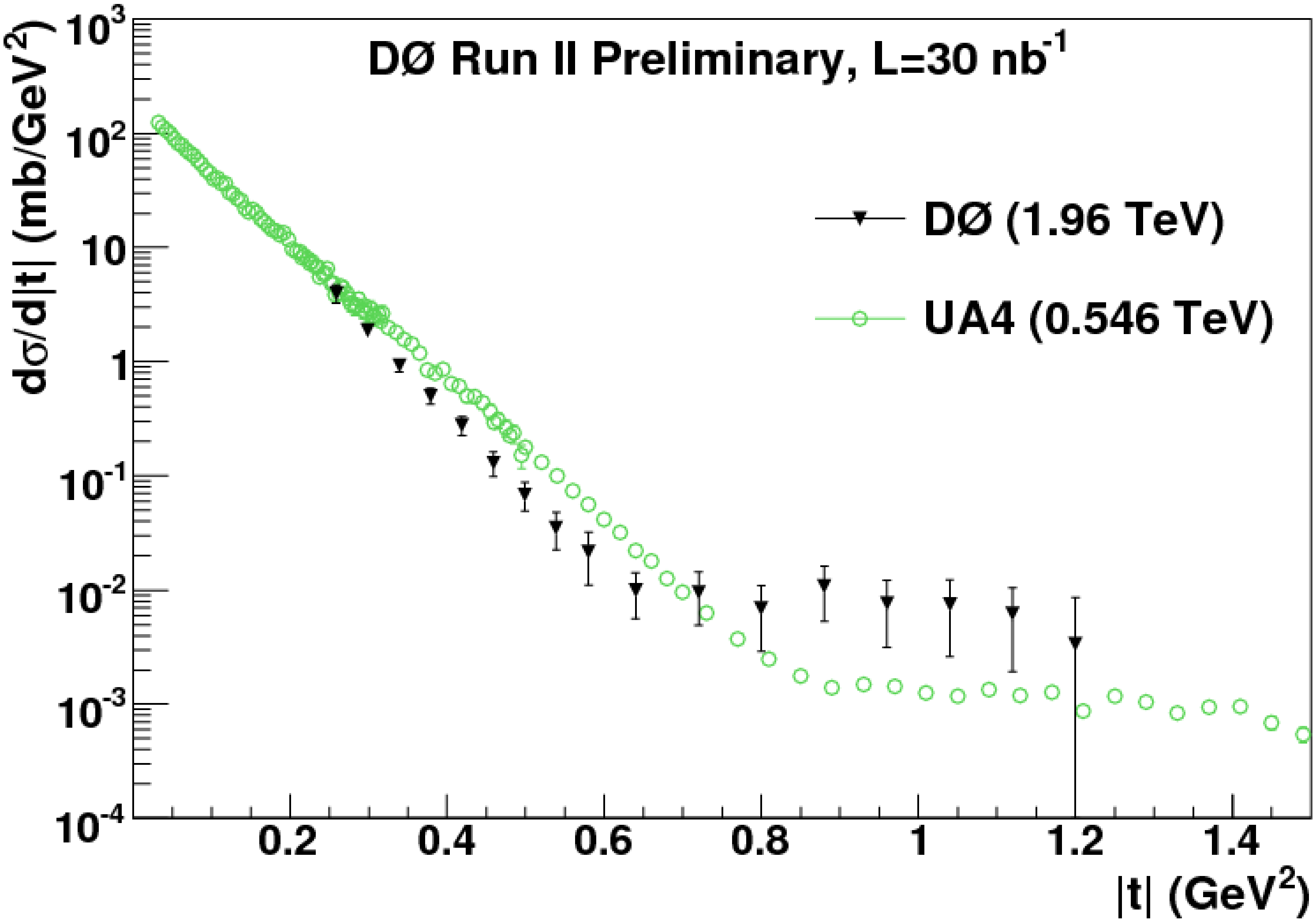
First measurement of b at $\sqrt{s}$=1.96 TeV

dσ/d|t| Compared to E710+CDF



E710/CDF for √s=1.8 TeV; GeV^2 expect logarithmic dependence with √s

dσ/d|t| Compared to UA4



Slope steeper and slope change earlier for higher √s (shrinkage)

Elastic Conclusions

- **We have measured $d\sigma/d|t|$ for elastic scattering over the range: 0.2< |t| <1.2 GeV^2 the first such measurement at $\sqrt{s}$=1.96 TeV**

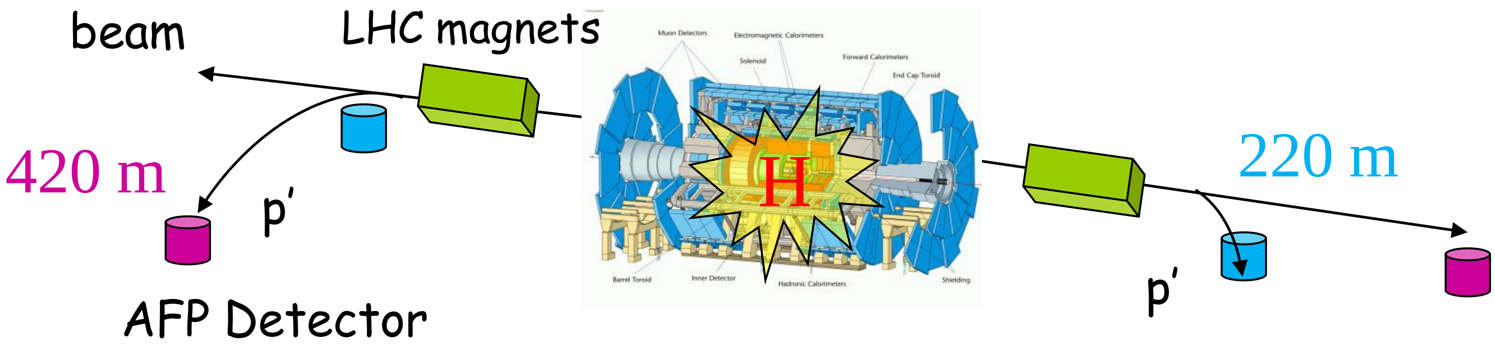
- **For 0.2<|t|<0.6 GeV^2 we have measured the elastic slope**
  b=16.5 ± 0.1 ± 0.8 GeV^{-2}

- **We observe that the elastic slope is steeper and changes slope earlier than lower energy data such as UA4**

- **Future plans: paper coming soon, inclusive SD results fairly mature, DPE results in pipeline**

High Mass Exclusive Dijets Motivation

ATLAS and CMS have proposals to add far forward proton detectors upstream and downstream of central detector to precisely measure the scattered protons to complement the LHC discovery program.

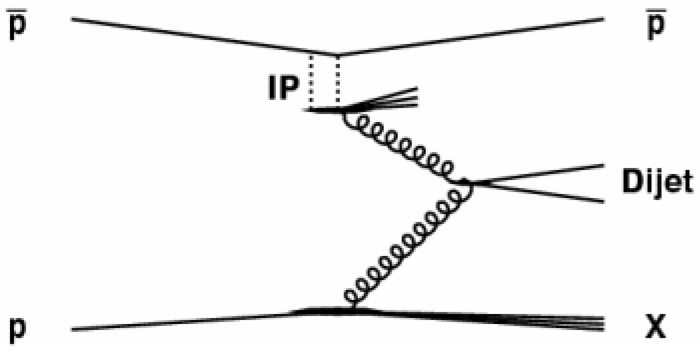


- Proposal studies pp→pΦp where Φ could be Higgs or other resonance, using precise measurement of protons to improve signal to background, and ultimatley measure Higgs mass and quantum numbers
- High mass dijet observation is an important step to validate the theoretical predictions for this process.

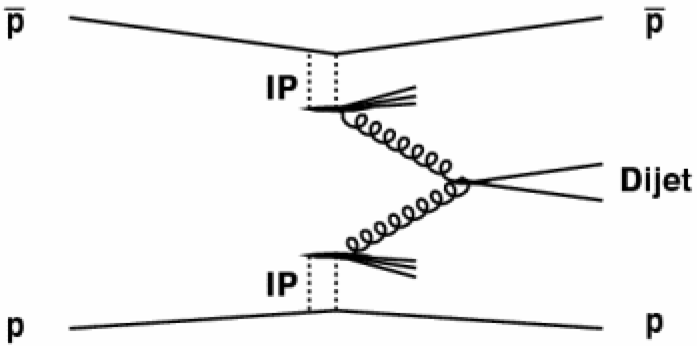
Signal and Background Processes

In addition to standard non-diffractive (NDF) QCD dijet production via quark or gluon exchange, jets can be produced via

Single Diffraction (SD)

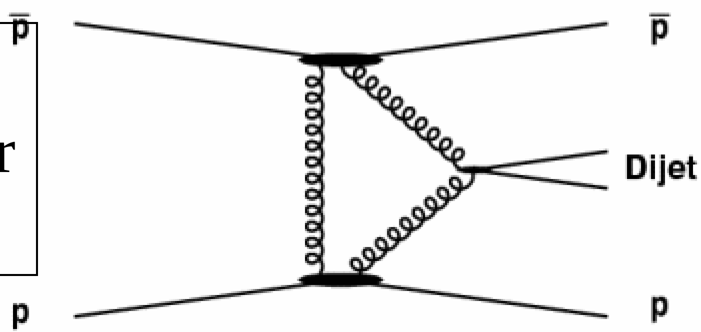


"Inclusive" Double Pomeron (IDP)



Exclusive Diffraction Production (EDP)

Are you sure that DP does not stand for double pomeron?



Aka CED or CEP (Central exclusive Diffraction/Production)

Exclusive Diffractive Production

- Entire momentum loss of proton is used to produce central system
- The process has been observed by CDF …

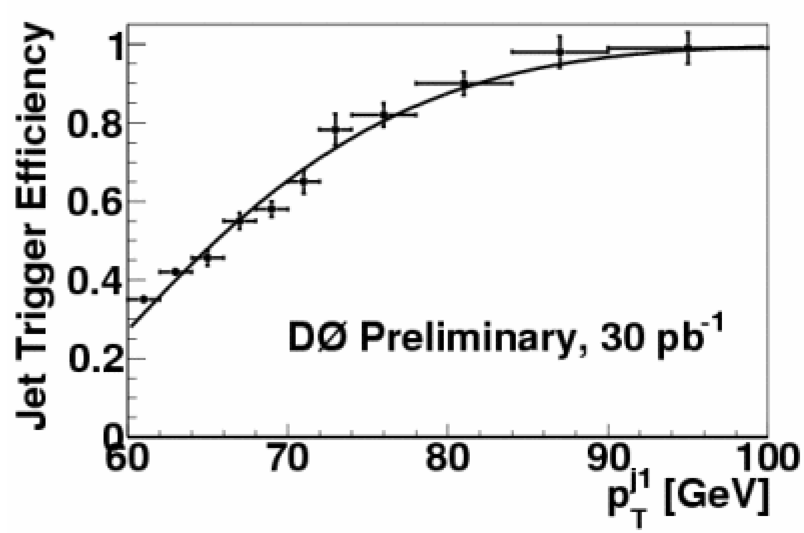
1) Observation of exclusive dijets : (CDF) PR D77, 052004 (2008)
   σ(excl, jetETmin = 15 GeV) 112+84-50 pb. In agreement with ExHuME MC which incorporates Khoze, Martin, Ryskin (KMR) model for EDP

2) Observation of exclusive χ_c : (CDF) PRL 102, 242001 (2009)
   $d\sigma/dy(y=0)$ = 76 +/- 10 +/- 10 pb. Prediction (KMRS) = 90 pb

but not for high mass systems O(100+ GeV)

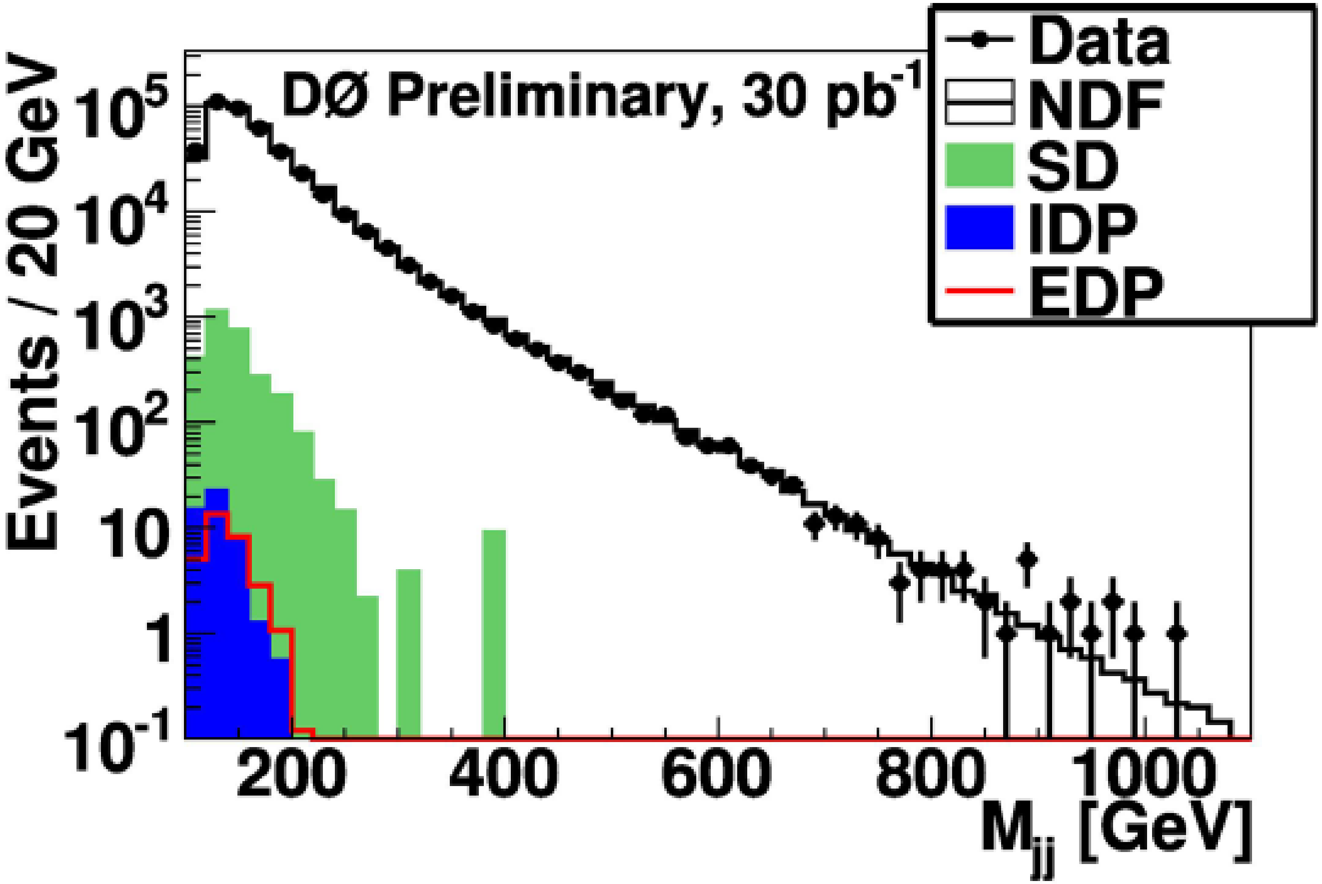
Data Sample

- Use inclusive jet trigger with $p_T > 45$ GeV



- Restrict instantaneous luminosity to low luminosity data (to control multiple proton anti-proton interactions)
- Integrated luminosity of sample is 30 pb^{-1}
- Two jets: $|y_{1,2}| < 0.8$, $p_{T1} > 60$ GeV, $p_{T2} > 40$ GeV, $M_{jj}>100$ GeV, $\Delta\varphi>3.1$

Dijet Invariant Mass



MC models:

NDF = Pythia

SD = Pomwig

IDP = FPMC

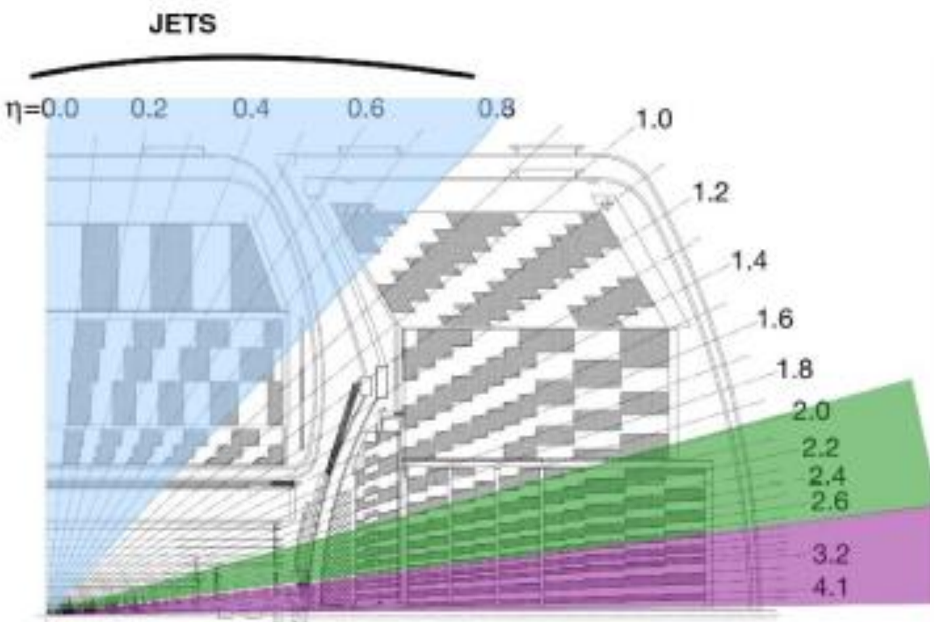
EDP = FPMC

Inclusive dijet invariant mass dominated by non-diffractive jet production

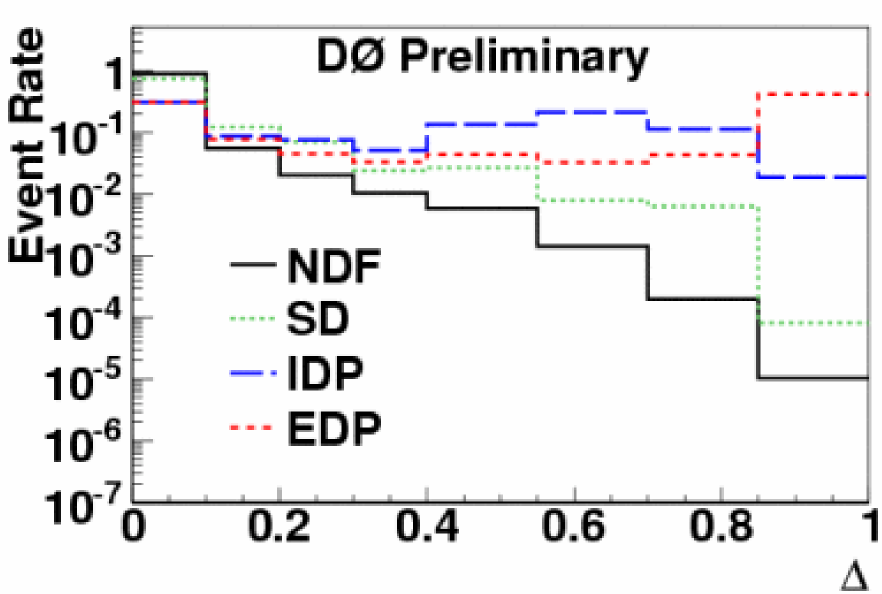
Distinguishing EDP Signal from Background

Separation variable: sum of energy of calorimeter cells

$$\Delta = \boxed{\frac{1}{2}\exp\left(-\sum_{2.0<|\eta|\leq 3.0} E_T\right)} + \boxed{\frac{1}{2}\exp\left(-\sum_{3.0<|\eta|\leq 4.2} E_T\right)}$$

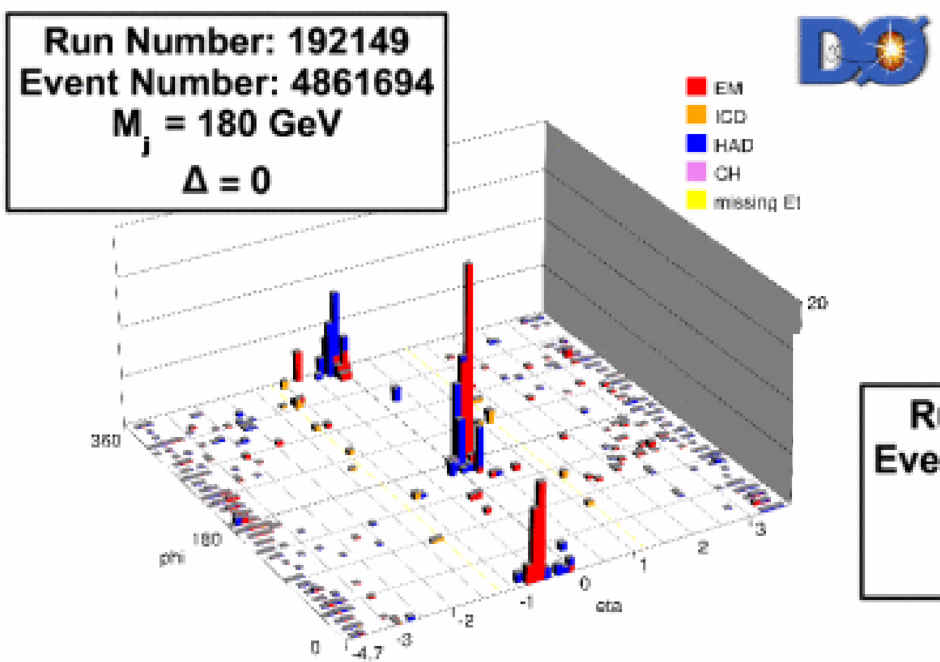


Discriminate against IDP
Discriminate against NDF



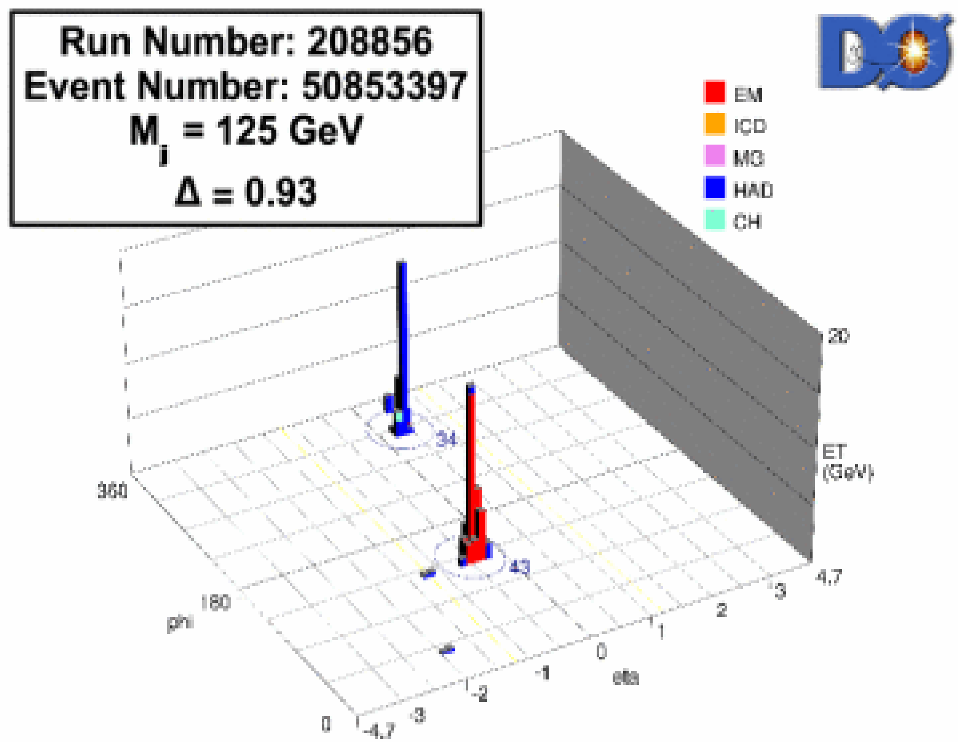
For two rapidity gaps Δ=1

Event Displays



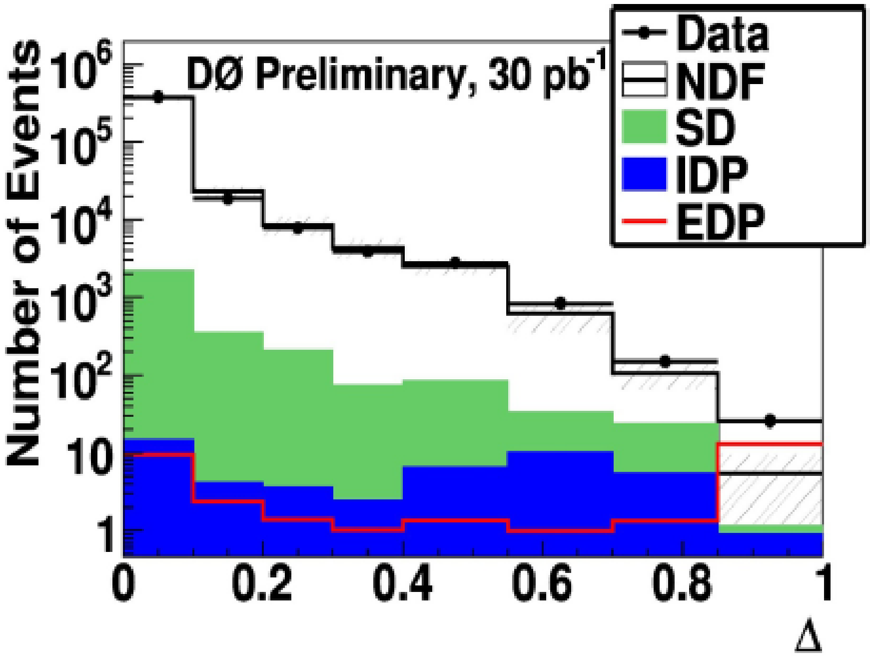
Not an EDP candidate

An EDP candidate



Δ Distribution

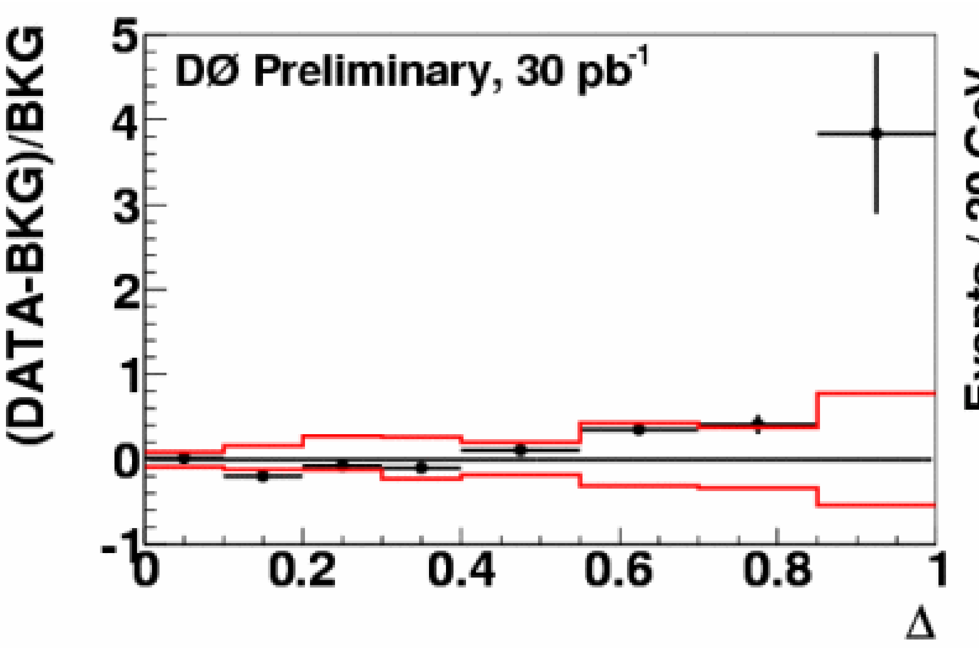
Observe 26 events with Δ>0.85 well over background expectations of $5.4^{+4.2}_{-2.9}$

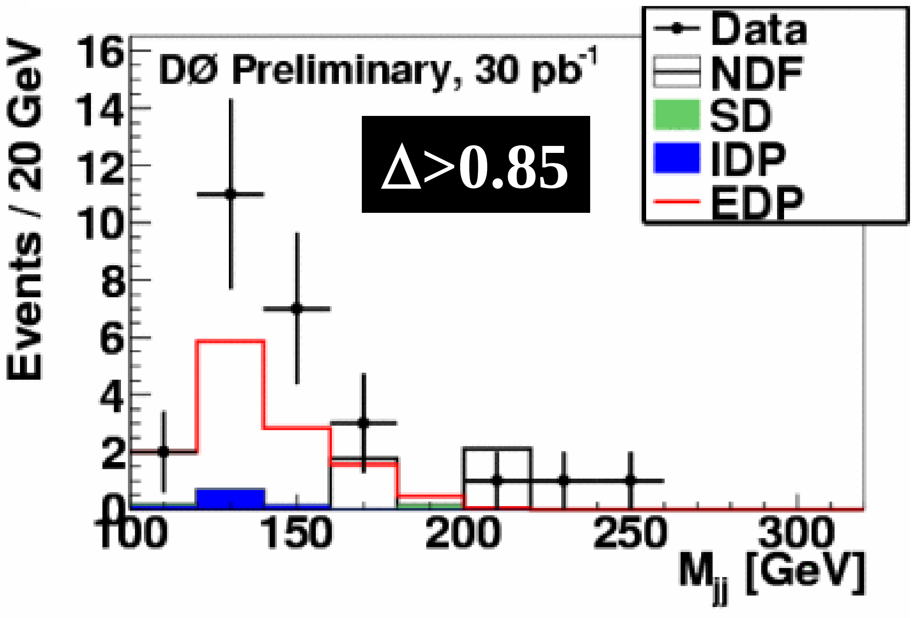


Modified frequentist method to estimate the significance of the excess:
Form pseudoexperiments with s+b and b-only hypotheses – count how many times b-only produces cross section seen in data – $2*10^{-3}\%$ => 4.1σ

Sample	Non-diffractive (NDF)	Single diffraction (SD)	Inclusive diffraction (IDP)	Exclusive Diffraction (EDP)	Data
No Δ cut	409527±24056	48.3±24.3	2930±1474	30.9±1.8	412505
Δ>0.85	4.2±1.6	0.9±0.4	0.2±0.2	12±0.9	26

Isolating Δ>0.85 Excess





Shape is in good agreement with EDP model, normalization within factor of two

Systematic Uncertainties

- Taken into account in estimating the significance:
- Cell calibration – 25%
- Jet energy scale uncertainty – 12%
- Trigger&luminosity reweighting – 3%
- MC to data normalization – 5%
- Additional uncertainty on SD&IDP MC normalization – 50%

Exclusive Conclusions

- First evidence for high mass exclusive dijet events (4.1σ excess for M_{jj}>100 GeV)

- Promising result for Higgs studies at LHC using proton tags